Renewable and Sustainable Energy Reviews 15 (2011) 3229–3236

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Zero carbon buildings refurbishment––A Hierarchical pathway

Yangang Xing[a,*], Neil Hewitt[b], Philip Griffiths[b]

[a] Welsh School of Architecture, Cardiff University, Bute Building, King Edward VII Avenue, Cardiff CF10 3NB, Wales, UK
[b] Centre for Sustainable Technologies, University of Ulster, Newtownabbey, BT37 0QB, UK

ARTICLE INFO

Article history:
Received 17 December 2010
Accepted 6 April 2011

Keywords:
Building refurbishment
Zero carbon
Renewable applications

ABSTRACT

Buildings account for almost half of energy consumptions in European countries and energy demand in building continues to grow worldwide. Fossil fuels are finite reserves. Impacts of peak oil will be perceived soon or later in the next decades. The scale of the challenge in reducing fossil fuel dependency in the built environment is vast and will require a dramatic increase in skills and awareness amongst the construction professions. Building refurbishment towards zero carbon is established itself as one critical aspect to decouple from fossil fuels and tackle with future energy crisis. However, it is a very complex phenomenon cuts across disciplines. This paper categorises a range of technologies for building refurbishment in a sequential manner. A hierarchical process with embedded techniques (insulations, energy efficient equipment and micro-generation) is presented in this paper as a pathway towards zero-carbon building refurbishment.

Contents

* Corresponding author. Tel.: +44 0 28 903 68635; fax: +44 0 28 903 68239.
E-mail addresses: xygnet@hotmail.co.uk, xingyangang@hotmail.com (Y. Xing).

1364-0321/$ – see front matter
doi:10.1016/j.rser.2011.04.020

1. Introduction

In EU, shifting away from heavy industry towards service sector activities, building has become the largest sector in terms of energy consumption. Currently buildings still rely on fossil fuels for energy supply. Yet buildings presently account for some 45% of carbon emissions and it has been estimated that 80% of the buildings that we will be occupying in 2050 have already been built [1]. Although the definition of zero carbon is still subject to future clarifications, the UK government has set up goals in delivering new zero carbon buildings [2,3]: Zero carbon dwellings and schools form 2016; zero carbon public sector building from 2018; Zero carbon commercial building from 2019. However, zero carbon new buildings have limited impacts on overall carbon reduction. New buildings only add roughly less than 1% to the stock in UK a year. Existing buildings represent the greatest opportunity for efficiency improvements and sustainable development.

Building refurbishment towards zero carbon faces tremendous technical challenges. Recent papers [4–6] examined new zero carbon buildings. A number of researches is carried to explore low carbon building techniques and issues [7–9]. Several assessment tools, such as PassivHaus [10], Code for Sustainable Homes, Ecohomes from BRE (reviewed in [11]) offer sets of criteria to evaluate a building design. Nevertheless, there is still a lack of specific and rigours process for zero carbon building refurbishment.

Based on a review in existing UK building stocks and refurbishment techniques, the authors developed a hierarchical pathway incorporating categorized techniques in a sequential process. A goal of this a hierarchical pathway is to minimize energy demand and match energy demand with local renewable energy supply. The authors argue that this pathway is a key to a successful refurbishment project totally decoupling a built environment from fossil fuels. It can offer a clear vision and choices of refurbishment techniques for relevant stakeholders involved in building sectors and policy analysis domain.

2. Building energy end uses in UK

Since 2000, close to 80% of the total working population in UK were employed in the service sector. The increased number of employees has resulted in an increase in floor area requiring more energy for space heating. In the year 2007, close to 80% of energy consumed in services sectors are for space heating, lighting and cooling [12]. As show in Fig. 1, at 2007 in UK, space heating accounts for 25% of overall energy consumptions, followed by other building related energy uses, such as water heating for 9%, lighting and appliances – for 7%, and cooking for 2%. According to this calculation, building energy uses account for 43% of overall energy uses in 2007 in UK. Domestic energy consumption has increased by 32% since 1970 and by 19% since 1990 [12]. As in 2007, space heating accounts for 56% of domestic energy consumption. Since 1990 the number of households has increased by 10%, population has increased by 4% and household disposable income has increased by 30%. Between 1970 and 2000, energy consumption in lighting and appliances increased by 15%, while energy use in cooking has fallen by 16%. Energy efficiency improvements, such as increased levels of insulation and the introduction of more efficient electrical appliances, have meant that domestic energy consumption has not increased at a greater rate.

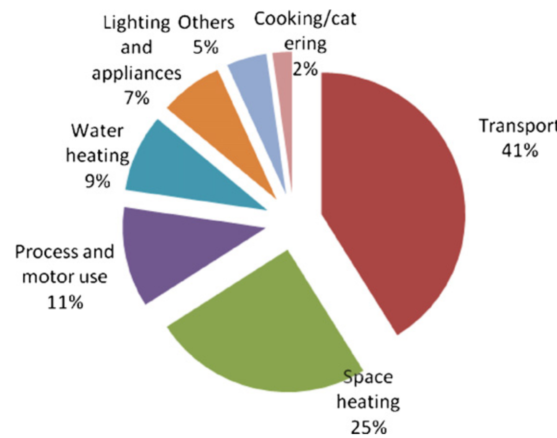


Fig. 1. Overall energy consumption in UK 2007
Source: Department of Energy and Climate Change – secondary analysis of data from the Digest of UK Energy.

There is a clear trend that older properties have much lower energy performance. It is estimated there are approximately 9.2 million dwellings (43%) in England with features are difficult to refurbish (i.e. solid wall, no loft space or off-main gas supply), 84% of this group is in the private sector. Solid wall properties and those off the mains gas network makes up the majority of the hard to treat stock [13]. Solid wall properties include traditional 9" (about 23 cm) masonry, single leaf masonry, concrete walls, metal panelled walls and timber panelled walls. It has been pointed out and over half the existing housing stock in the UK has inadequate levels of insulation [14]. It can be seen in Figure 2 that only very small proportion of existing buildings are achieved energy efficiency rating (above 86 in SAP 2001rating scale [15]). SAP modelling tool have been subsequently updated, however it remains as an insufficient tool to provide an insightful guidance for zero-carbon building refurbishment. In summary, there is a lack of a clear pathway enable relevant stakeholders to effectively tackle the complex phenomenon and significantly reduce carbon emission in building sectors.

3. A hierarchical process towards zero-carbon buildings refurbishment

Building refurbishment is a complex undertaking cutting across different technical fields and facing challenges in incorporating renewable energy in a built environment.

Although the definition of "zero carbon building" is still subject to further wider consultations and consensuses, but it would be practical to define the concept base a set of criteria in a hierarchical stages, such as insulation, building services and microgenerations. The authors established a hierarchical approach to achieve zero carbon refurbishment. The first step is to reduce energy demand by retrofitting building fabrics to higher standards; the second step is to install energy efficient equipments, the last step is to establish on-site low and zero carbon energy supply technologies with smart grid connections and control as shown in Fig. 3. Indeed, zero-carbon building as a dynamic concept can be explored at different stages in whole life cycle of building. Embedded energy at up-stream carbon emission, on the other hand, material disposal at down stream phases are very important when examine whole life cycle impacts of a building as discussed

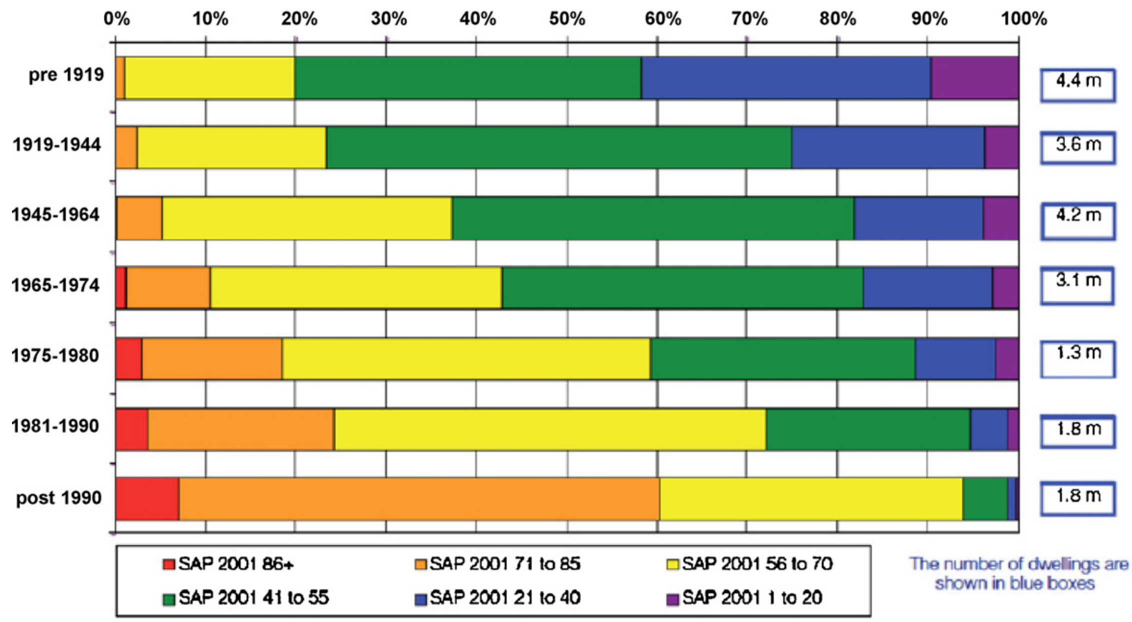


Fig. 2. Energy efficiency in existing dwellings stock [13].

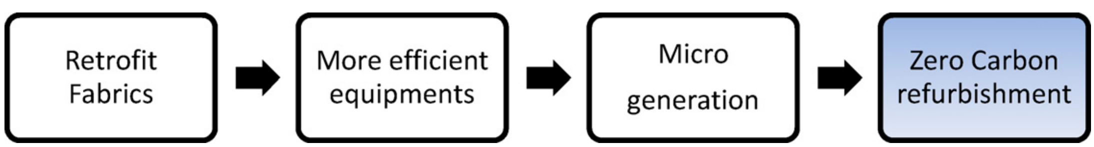


Fig. 3. A hierarchical process towards zero carbon refurbishment.

in a previous research [11]. However, a very specific purpose of this paper is to investigate technical aspects of building refurbishment to reduce operational energy consumption and decouple building energy systems from fossil fuels. From energy assessment point of view, this process will reinforce refurbishment project to focus on energy conservation and demand reduction. The key indicators include energy demand and renewable energy penetrations. This hierarchical process (Fig. 3) can help to reduce the complexity in carrying out a refurbishment project. It will allow architects, engineers or buildings to prioritise the most important design considerations at each design stage rather than consider all together as in a 'flat' model. In the following sections, current advances and emerging techniques for zero carbon refurbishment are reviewed.

4. Retrofit building fabrics

4.1. Current best practices

Space heating is the largest building energy end use. To retrofit building fabrics is vitally important to reduce energy demand in buildings. External insulation is often the desired solution for insulations for solid walls. External solutions usually comprises of an insulation layer fixed to the existing wall, such as a protective render or decorative cladding. Timber panels, stone or clay tiles, brick slips or aluminium panels are often used for cladding. Benefits of external wall insulation for solid walls include no internal living space loss, minimum disruption, and condensation risk is reduced. However, in some cases, internal insulation is the only option available, such as for the purposes of maintaining original façade features in historical buildings. Internal solid wall insulation typically consists of either dry lining in the form of flexible thermal linings, laminated insulation plasterboard (i.e. thermal board), or built-up system using fibrous insulation such as mineral wood held in place using a studwork frame. Cavity Wall insulation (CWI) is one effective energy efficiency measure. It usually only takes a few hours to install depending on the size of the house or and other factors, such as access and preparations. In UK, commonly used insulation materials include mineral wool, expanded polystyrene bead (EPS Bead), and Urea formaldehyde foam (UF Foam). The three materials have roughly equivalent thermal insulation properties, and are resistant to water penetration by capillary actions. Cellulose insulation – organic plant fibber is another useful material, but its performance can be compromised if it comes into contact with moisture. Water vapour barrier is often used in internal insulation to avoid condensations. A study also shows that a hydrophilic mineral wool can perform very well in terms of thermal insulation and condensation reduction for an internal insulation [16–18]. It is noticed that quality assurance and specifications were found to be important, especially to ensure insulation materials to be installed with a manner of homogeneously distribution and constant density.

Many buildings leak heat through gaps in the joins of their windows or doors. Heat losses by ventilation can be strongly reduced by improving the air tightness of the building. Draught proofing is one of the most inexpensive and effective energy efficiency measures. The different types of materials include brushes, foams, sealants, draught excluders, and tapes. Heat loss from loft is considered as one important aspect to address. Most UK loft insulations are around 150 mm or less of flexible insulation slabs [14], which require significant increase in extra loft insulations. Benefits which green roofs can offer in winter heating reduction as well as summer cooling in building retrofitting projects are reviewed and discussed [19]. Detailed assessment of the roof conditions and green roof

materials need to be future investigated in order to device a sustainable green roof retrofitting solutions.

A number of buildings were refurbished to high level of thermal performance, e.g. the PassivHaus standard [20], which has two key requirements for energy demand: space heating energy demand lower than 15 kWh/m^{2}yr, and total primary energy demand lower than 120 kWh/m^{2}yr. PassivHaus requirements can be met by super insulations and heat recover systems with overall heat transfer coefficient of only about 0.1 W/m^2. Based on a review of certified PassivHaus projects [10], on average, u-value for exterior walls is around 0.11 W/m^{2}k, for roof is around 0.13 W/m^{2}k and or floor is around 0.086 W/m^{2}k, less then one third of the current building regulations [21] (Part L – Conservation of fuel and power) in UK. By having really good insulation it allows the building to retain the heat that is generated within the house by activities (cooking, electrical goods, people's body heat etc.) and also via passive means (direct solar gain or heat stored in thermal mass). Nevertheless, current higher level of thermal insulations proposes challenges in cost and extra space required for thicker building envelops. Section 4.2 summarised emerging high performance thermal building insulating materials which can offer much higher thermal resistance with thinner insulation.

4.2. Emerging insulation materials

It is perceived that wall thickness of well insulated buildings is typically exceeding 600 mm. Continuous increase of insulation thickness can result in more complex design, construction, maintenance, an adverse net-to-gross floor area and possible heavier load bearing constructions. Thus, a range of lower λ (thermal conductibility) insulation materials have been developed and utilised, such as aerogel, multi-layer insulation, transparent insulation, gas filled insulation, and vacuum insulation.

4.2.1. Aerogel

Aerogel has been studied extensively in the last few decades [22–24] as an insulation materials owing to its low thermal conductivity. Aerogel materials tend to have less than 0.013 W/mk thermal conductivity. It only requires less than one tenth of the thickness of traditional insulation materials, which makes it very attractive insulation materials for refurbishment as. Aerogel filed insulation panels as commercial products are installed in building refurbishment projects in UK.

4.2.2. Multiple-layer insulation

Multiple layers of insulation are usually used to achieve better thermal performance. One early example is so-called multi-foil films consist of a series of reflective layers interspersed with layers of wadding and foam. It is expected that low levels of heat transfer can be achieved based on their ability to reflect longwave radiative (also called infrared radiation) energy. However, it has noticed that multi-foil products performance degrade over time as dust accumulating on the surface will diminish its performance. A research shows a complicated 19-layers foil films insulation material with best possible materials do not obtain a lower u-value than 200 mm of mineral wool insulation [25].

4.2.3. Transparent insulation materials (TIS)

It reported that transparent insulation materials (TIS) can allow solar energy transmittance of more than 50% and thermal conductivity of less than 0.2 W/m^{2}k [26,27]. Transparent insulation materials can be produced by utilising different type optical absorber or cavity structures. Generally, overheating control and cost issues are the two major issues associated with transparent insulation.

4.2.4. Gas-filled panels (GFPs)

Gas-filled panels (GFPs) consist of a barrier envelope and a gas between reflective layers (a baffle). The gas can be air or a heavier gas to decrease thermal advection and conduction. A low-emissivity barrier envelope is used to enclose the gas and to decrease the heat transfer due to radiation, while a low-emissivity baffle structure is included to decrease inner gas convection and radiation. However, compared with other high performance thermal insulation materials and solutions, e.g. vacuum insulation panels (VIPs), the future of GFPs may therefore be questioned [28].

4.2.5. Vacuum insulation

Vacuum insulation uses the insulating effects of a vacuum to produce much higher thermal resistance than conventional insulation. Vacuum insulation panels (VIPs) are regarded as one of the most promising high thermal performance insulation solutions on the market. Research revealed that if optimized kernels and barrier laminates as well as stringent quality control are employed, a centre u-value of 0.2 W/m^{2}K can be achieved for a VIP thickness of only 2 cm [29]. It has a thermal resistance about a factor of 10 higher than that of equally thick conventional polystyrene boards or mineral wool fibres. Vacuum insulation can enable think, high insulation construction for walls, roofs and floors. Vacuum insulation has been used for building refurbishment projects where available spaces are restricted for thicker thermal insulation [30]. It is noted that quality control of VIPs is a very important issue [31]. Feasible paths beyond VIPs are investigated and possibilities such as vacuum insulation materials (VIMs) and nano insulation materials (NIMs) [32]. Vacuum glazing systems with very low u-values have employed multiple glass panes, inert gases and numerous low emittance coated surfaces [33,34]. These systems usually require three or more panes of glass and are twice as wide as standard double-glazing. It can be expected that within the trend of rising energy costs, high performance thermal building insulating materials may have great potential in the housing refurbishment market.

5. High energy efficient building services equipments

5.1. Lighting sources

5.1.1. Low energy lighting

It is estimated that electrical lighting constitutes 30% of total domestic electricity consumptions and 19% of global electricity use, and [35,36]. It is suggested that lighting energy use can be reduce by 75–90% compared to conventional practice through combing daylighting, energy efficient lighting and control [37]. Conventional incandescent lights can only convert 5% of the input energy and rest being converted into waste heat. Currently, LEDs already achieve up to 100 lm/w. Replacement of inefficient lamps is usually the first choice for low carbon refurbishment due to facts of significantly reduction of electricity usage with relatively cheaper means.

5.1.2. Passive lighting sources

Apart from low energy lighting, passive methods have been explored to improve daylighting penetration and visual comfort, e.g. passive solar glazed sunspace. It usually takes the form of a conservatory or glazed balcony which has been encouraged as a low-energy feature in refurbished buildings. However, doubts have been raised previously as to whether any real energy savings are possible and whether in fact these spaces increase energy consumption. Researchers [38] argued that sunspaces can be an appropriate and effective system all over Europe during the winter. It demonstrated that sunspace can be an effective way to ensure good daylighitng in a refurbished high-rise social housing building in Germany [39]. Nevertheless, glazing materials have higher

heat transfer coefficient causing heat losses in winter and overheating problems in summer, especially roof window which can admit direct solar gains. Better performing glazing materials can also reduce overheating problems. It revealed aerogel glazing can provide up to 7% cooling energy saving in some buildings in hot climate [40]. Aerogel as a replacement material for windows has been investigated based on the assumption that it can offer improved thermal insulation properties over the best-performing glazing systems. However, some technical issues remain to be solved such as fragility and lack of complete transparency for lights transmission. It has been reported that developed monolithic silica aerogel glazing has a total solar energy transmittance (*g*-value) higher than plain double glazing and at the same time has a heat loss coefficient equal to the best triple layered gas filled glazing units [41].

5.1.3. Electrochomistic materials

Electrochromism is the phenomenon displayed by some materials of reversibly changing color when a burst of charge is applied. Electrochromic materials are used to control the amount of light and heat allowed to pass through windows. Electrochromic devices are essentially multilayer electrochemical cells characterized by the ability of changing reversibly their optical transmittance under the action of a low electric field, thus providing responsive and dynamic modulation of the thermal and optical properties of the buildings' glazed surfaces [42,43]. One example of an electrochromic material is polyaniline which can be formed either by the electrochemical or chemical oxidation of aniline. Polymer-based solutions have recently been developed with the promise to provide flexible and cheap electrochromics in a variety of colors [44]. Energy saving potential of these devices regarding optimized solar heat gain, daylight control and occupants' comfort has been investigated and some beneficial impacts of using electrochromic are being verified [45–47]. From an energy conservation perspective it is better to have windows in their low-transparent state whenever there are cooling needs. One type of switchable glazing uses an electrochromic film to control the transmittance and reflectance of the glass: clear glass with high transmittance or dark glass with low transmittance [43]. However, it has been noticed that, high visible transmittance is still needed even external temperature is very hot. An occupancy-based control system is proposed and evaluated [48] in preventing glare, and at the same time allowing the occupants to access to suitable daylights by limiting the perpendicular component of the incident solar irradiation to avoid glare. Smart windows technology sets off the potentials of future improving glassing products and building control systems. Monitoring and evaluation of the performance of smart windows is a key to established impacts of new glazing techniques on whole building performance.

5.2. Heating sources

Heating accounts for about 40% of final energy consumption (around 85% of domestic energy consumptions) in UK in the year 2009 [12]. In this section, heating technologies (solar panels, heat pump, CHP, biomass boilers, district heating and thermal storage) are reviewed.

5.2.1. Solar thermal

Solar thermal collectors have been the favourite technique in utilising renewable energy. There are two dominant collector types: vacuum tube collector with higher energy efficiency accounts for more than half of global market share and followed by flat-plate collectors with more than 30% global share. They both are primarily suitable for preparing hot water and to providing space heating. There are great potential of solar energy can be harvested for buildings [49].

5.2.2. Biomass

Biomass for energy could reduce carbon life cycle and Greenhouse Gases (GHG) emissions from the combustion of fossil fuels and diversify energy supply at reasonable costs. Biomass is, therefore, preference heating sources for low energy buildings [50]. The efficiency of biofuel systems tends to be lower than that of fossil energy systems. However, recent technological developments have increased the efficiency of bioenergy systems considerably (e.g. Biomass Integrated Gasification Combined Cycle – BIGCC) [50]. Nevertheless, researchers and practitioners disclosed concerns surrounding the sourcing, processing, transporting of biomass fuel, and increases in NO_x and particulate emissions as a result of biomass boilers [51,52].

5.2.3. Heat pumps

Heat pumps as renewable energy supply recover heat from different sources for use in domestic and non-domestic buildings. Air source heat pumps are considered as better options for building refurbishment due to its ease of installation and less space requirement comparing with ground source heat pumps. Recent progresses in heat pump systems have centred upon advanced cycle designs and cycle components (including choice of working fluid), and exploiting utilisation in a wider range of applications. Some recent research efforts have markedly improved the energy efficiency of heat pump, e.g. to optimize heat pump system to supply domestic hot water and complex space heating [53,54]; optimize the efficiency of an air source heat pump operation under a range of conditions through a series defrosting cycles [55]; and incorporation of a heat-driven ejector to the heat pump improving system efficiency by more than 20% [56]. However, a recent relatively large-scale field trial of domestic heat pumps in the UK has found that its performance is very sensitive to installation and commissioning practices [57]. In the USA, according to a survey that more than 50% of all heat pumps have significant problems with low airflow, leaky ducts, or incorrect refrigerant charge [58]. Heat pumps are still relatively new techniques in UK housing refurbishment markets. Better understanding of heat pumps seasonal performance, installation and operational issues is required for higher penetration of heat pumps in housing refurbishment market.

5.2.4. Combined heat and power (CHP)

Combined heat and power (CHP) utilising the waste heat produced during the generating of electricity has a critical role to play in reducing emissions and increasing the use of renewable energy. CHP can improve efficiency by over 30% comparing to generating heat and electricity separately. It can also be used to provide low carbon cooling. Using CHP to provide cooling can make CHP more economically attractive as it provides a use for heat year- round and improves the efficiency of operation of the plant.

5.2.5. District heating

District heating is a system for distributing heat generated in a centralized location for heating requirements such as space heating and water heating. District heating plants has been expected to provide higher efficiencies and better pollution control than localized heating sources due to the factors that district heating system will be more likely to be maintained, operated and controlled more professionally, especially through District heating schemes are not as common in the UK as in some other EU countries. However, the UK government has developed a policy framework to encourage the deployment of district heat networks in local communities [3]. A

number of techniques were proposed to improve efficiency of a district heating system including scheduling pipe installation, flexible piping, and optimisation to reduce investment and operational cost [59]. Sparsely distributed housing stocks proposed challenges in implementing district heating systems, mainly due to high connection costs. However, researchers suggested that profitable sparse heating system in Sweden is possible. It was noticed the importance in developing business logic and effective customer interactions [60]. Combining gradual expansion of district heating with individual heat pumps in remaining houses is found to be the most likely scenario of future renewable energy systems in Danish housing sector [61].

5.2.6. Thermal storage

Seasonal thermal storage can play a significant role in balance heat demand and renewable energy supply. One example is underground thermal energy storage (UTES). UTES is a well research area. A research carried out in Anneberg, Sweden shows and solar heating systems coupled with UTES provide 60% of total heat demand (space heating and domestic hot water) [62]. The Anneberg residential area consists of 90 building units of 100 m^2 each. It was shown that 3000 m^2 of roof-mounted solar collectors and borehole storage system of 6000 m^2 (99 boreholes, borehole depth 65 m). Underground cold-water reservoir for passive cooling purposes in hot arid regions is explored [63]. Phase change materials (PCMs) can prove lantern heat in shorter term. Passive applications include the addition of microencapsulated PCM impregnated in wall board, which will act to offset air-conditioning plant by allowing the wall/ceiling system to absorb heat at for example 25 °C thus effectively acting as mass and slowing the response of the building to solar gains. PCM can offer a more compact solution than water with marginal costs (estimated at around £2/kg). Researchers [64] have also explored possibility in using hydrogen as seasonal storage mechanism for low energy buildings.

5.3. Ventilations

5.3.1. Natural ventilation

Natural ventilation is considered as a powerful means to improve indoor air qualities. A number of researches reviewed and studied natural ventilations techniques such as night ventilations, thermal mass, shading devices (such as overhangs and side-fins), buried pipes and evaporative cooling [65–67]. Overheating is perceived increasingly as an issue needs to be adjusted in the last few decades, as increasing the thickness or thermal resistance of insulation, and reduce the ventilation rate of the building. With proper control system, natural ventilation techniques have great potentials to avoid overheating problems in buildings.

5.3.2. Mechanical ventilation

Mechanical ventilation with heat recovery (MVHR) is considered as more efficient than natural ventilation and can ensure better air quality [68]. A heat recovery system conserves energy by remove heat from extracted air to the incoming air. However, the seasonal performance of MVHR needs to be studied in details in ambient temperature and buildings' thermal properties to see whether heat gain compensates heat demand from a heat generator. Dynamic insulation as a concept means a construction where the air is being forced through the insulation from the colder outside air into the heated buildings. For conduction heat in the insulation is preheating the incoming air. Theoretical u-value of the integrated building envelop can be reduced towards zero if balance can be maintained between conduction heat losses in the insulation and heat gain in the incoming air. The concept of dynamic insulation is well known in Scandinavia and used in agricultural and residential buildings. Dynamic insulations in buildings refurbishment have been investigated to improve the thermal performance of building, and external architectural skin [69,70]. Ventilated facade is a system consisting of an external facade cladding, a sub-structure anchored to the wall surface of the building, an insulating material and an air gap between the cladding and the insulating material. The mass air flow inside the ventilated duct, due to the buoyancy effects, carries away heat load through natural convection especially during peak load hours of the day (when electricity costs more). In multi-stories buildings, ventilated façade has been identified as useful technique in cold climates during the heating season [71].

6. Micro-generation

The last technical step in this zero carbon refurbishment process is micro-generation. It has been anticipated that the impacts of peak oil will force building users to reply more and more on renewable heating/cooling sources. Most applications in daily life will rely on electricity and renewable heat energies. Consequently, future building energy system will progress dramatically to adapt renewable energy supplies. Micro-generation is the generation of zero or low-carbon heat and/or power to meet own energy demand on site. There is a wealth of micro-generation technologies: such as wind, solar, PV panels, and hydro, either commercially available or at an advanced stage of development [37,72–74]. Performance of micro-generation systems are found various widely from Manufacturers' quotes and laboratory studies owing to installation and operational problems [73]. Smarter control of a micro-grid can enable more dynamic 'real-time' flows of information on the micro-gird and more interaction between energy generation and consumption [75]. In building energy systems, loads that meet the communication and control requirements can be shifted to help manage the grid and with little impact on occupants. It can be processed by various mean, for examples using thermal storage, pre-cooling, and load shifting of non-critical equipments. Through proper application of demand-side management (DSM) technologies, it is possible to reduce the need of new installed intermittent power to achieve the renewable penetration targets and match power generation to consumer demand [76–78]. It is noted that it is important to develop integrated simulation model to facilitate future research in load shifting, transient stability, protection and control strategies.

7. Conclusions

Fossil fuels are finite resource, which will run out soon or later. Zero carbon refurbishment is proposed to decouple built environment from fossil fuels and integrate with local renewable energies. However, zero carbon refurbishment is a very complicated task involving a range of advanced technologies. It is facing challenges in promoting awareness and increasing relevant skills sets among relevant stakeholders. In this paper, advanced technologies are reviewed and categorised in sequential manner as a hierarchical pathway. Key technologies reviewed include building insulations, high efficient building services equipments (lighting, heating and ventilation), and micro-generation. The illustrated hierarchical pathway towards zero-carbon refurbishment can help designers and engineers to reduce complexity by prioritising design considerations at each stage in design and evaluation process.

Acknowledgement

The financial support of Irish Cross Border programmes is gratefully acknowledged.

References

[1] RAENG, Engineering a low carbon built environment: the discipline of building engineering physics; 2010.
[2] Hanmer C. Energy and low carbon buildings in the United Kingdom. IEA ECBCS News. 51; 2010.
[3] DECC, An enabling framework for district heating and cooling, department of energy and climate change (DECC); 2009.
[4] Voss K, Goetzberger A, Bopp G, Häberle A, Heinzel A, Lehmberg H. The self-sufficient solar house in Freiburg—results of 3 years of operation. Solar Energy 1996;58:17–23.
[5] Zhu L, Hurt R, Correa D, Boehm R. Comprehensive energy and economic analyses on a zero energy house versus a conventional house. Energy 2009;34:1043–53.
[6] Wang L, Gwilliam J, Jones P. Case study of zero energy house design in UK. Energy Build 2009;41:1215–22.
[7] Reeves A, Taylor S, Fleming P. Modelling the potential to achieve deep carbon emission cuts in existing UK social housing: the case of Peabody. Energy Policy 2010;38:4241–51.
[8] Omer AM. Focus on low carbon technologies: the positive solution. Renew Sustain Energy Rev 2008;12:2331–57.
[9] Morrissey J, Moore T, Horne RE. Affordable passive solar design in a temperate climate: an experiment in residential building orientation. Renew Energy 2011;36:568–77.
[10] PassivHaus Institut, Built passive houses, http://www.passivhausprojekte.de/kriterien.php, PassivHaus Institut; 2010.
[11] Xing Y, Horner RMW, El-Haram MA, Bebbington J. A framework model for assessing sustainability impacts of urban development. Account Forum 2009;33:209–24.
[12] DECC, Digest of UK Energy-secondary analysis of data from the Digest of UK Energy, Department of Energy and Climate Change (DECC); 2009.
[13] DCLG, Review of the sustainability of existing buildings: the energy efficiency of dwellings—initial analysis; 2006.
[14] Marshall N. A guide to home insulation: how it can benefit your pocket and the environment by National Insulation Association (NIA), 2010; 2008.
[15] BRE, Standard Assessment Procedure (SAP)––The Government's standard assessment procedure for energy rating of dwellings, 2001 edition; 2001.
[16] Toman J, Vimmrová A, Černý R. Long-term on-site assessment of hygrothermal performance of interior thermal insulation system without water vapour barrier. Energy Build 2009;41:51–5.
[17] Pavlík Z, Černý R. Hygrothermal performance study of an innovative interior thermal insulation system. Appl Therm Eng 2009;29:1941–6.
[18] Pavlík Z, Černý R. Experimental assessment of hygrothermal performance of an interior thermal insulation system using a laboratory technique simulating on-site conditions. Energy Build 2008;40:673–8.
[19] Castleton HF, Stovin V, Beck SBM, Davison JB. Green roofs; building energy savings and the potential for retrofit. Energy Build 2010;42:1582–91.
[20] Feist W, Schnieders J, Dorer V, Haas A. Re-inventing air heating: convenient and comfortable within the frame of the passive house concept. Energy Build 2005;37:1186–203.
[21] DCLG. Approved documents and building regulations publications; 2010.
[22] Hümmer E, Rettelbach T, Lu X, Fricke J. Opacified silica aerogel powder insulation. Thermochim Acta 1993;218:269–76.
[23] Kamiuto K, Miyamoto T, Saitoh S. Thermal characteristics of a solar tank with aerogel surface insulation. Appl Energy 1999;62:113–23.
[24] Smith DM, Maskara A, Boes. U. Aerogel-based thermal insulation. J Non-Cryst Solids 1998;225:254–9.
[25] Eames P. Multi-foil insulation, Department for Communities and Local Government; 2009.
[26] Wong IL, Eames PC, Perera RS. A review of transparent insulation systems and the evaluation of payback period for building applications. Solar Energy 2007;81:1058–71.
[27] Haller A. Solar renovation concepts and systems - a report of task 20 "Solar energy in building renovation" Subtask F "Improvement of solar renovation concepts and systems"; 1999.
[28] Baetens R, Jelle BP, Gustavsen A, Grynning S. Gas-filled panels for building applications: a state-of-the-art review. Energy Build 2010;42:1969–75.
[29] Fricke J, Heinemann U, Ebert HP. Vacuum insulation panels—from research to market. Vacuum 2008;82:680–90.
[30] Armin B, Andre M. Vacuum insulation in the building sector––systems and applications; 2005.
[31] Caps R, Beyrichen H, Kraus D, Weismann S. Quality control of vacuum insulation panels: Methods of measuring gas pressure. Vacuum 2008;82:691–9.
[32] Baetens R, Jelle BP, Thue JV, Tenpierik MJ, Grynning S, Uvsløkk S, et al. Vacuum insulation panels for building applications: a review and beyond. Energy Build 2010;42:147–72.
[33] Fang Y, Hyde T, Hewitt N, Eames PC, Norton B. Thermal performance analysis of an electrochromic vacuum glazing with low emittance coatings. Solar Energy 2010;84:516–25.
[34] Fang Y, Eames PC. Thermal performance of an electrochromic vacuum glazing. Energy Convers Manage 2006;47:3602–10.
[35] Houri A, Khoury PE. Financial and energy impacts of compact fluorescent light bulbs in a rural setting. Energy Build 2010;42:658–66.
[36] Zissis G. CFL quality and strategies to phase out incandescent lamps, CEN Star trent analysis workshop; 2007. p. 1–10.
[37] Hinnells M. Technologies to achieve demand reduction and microgeneration in buildings. Energy Policy 2008;36:4427–33.
[38] Mihalakakou G. On the use of sunspace for space heating/cooling in Europe. Renew Energy 2002;26:415–29.
[39] Wilson MP, Jorgensen OB, Johannesen G. Daylighting, energy and glazed balconies: a study of a refurbishment project in Engelsby, near Flensberg. Germany Light Res Technol 2000;32:127–32.
[40] Bahaj AS, James PAB, Jentsch MF. Potential of emerging glazing technologies for highly glazed buildings in hot arid climates. Energy Build 2008;40:720–31.
[41] Schultz JM, Jensen KI, Kristiansen FH. Super insulating aerogel glazing. Solar Energy Mater Solar Cells 2005;89:275–85.
[42] Granqvist CG. Electrochromic tungsten oxide films: review of progress 1993–1998. Solar Energy Mater Solar Cells 2000;60:201–62.
[43] Yik F, Bojić M. Application of switchable glazing to high-rise residential buildings in Hong Kong. Energy Build 2006;38:463–71.
[44] Ece U, Pierre MB, Stefan E, June-Ho J, John RR. Black to transmissive switching in a pseudo three-electrode electrochromic device. Chem Mater 2009;21:5145–353.
[45] Piccolo A, Simone F. Effect of switchable glazing on discomfort glare from windows. Build Environ 2009;44:1171–80.
[46] Piccolo A. Thermal performance of an electrochromic smart window tested in an environmental test cell. Energy Build 2010;42:1409–17.
[47] Assimakopoulos MN, Tsangrassoulis A, Santamouris M, Guarracino G. Comparing the energy performance of an electrochromic window under various control strategies. Build Environ 2007;42:2829–34.
[48] Jonsson A, Roos A. Evaluation of control strategies for different smart window combinations using computer simulations. Solar Energy 2010;84:1–9.
[49] Thirugnanasambandam M, Iniyan S, Goic R. A review of solar thermal technologies. Renew Sustain Energy Rev 2010;14:312–22.
[50] Kalina J. Retrofitting of municipal coal fired heating plant with integrated biomass gasification gas turbine based cogeneration block. Energy Convers Manage 2010;51:1085–92.
[51] Zhang X, Kondragunta S, Schmidt C, Kogan F. Near real time monitoring of biomass burning particulate emissions (PM2.5) across contiguous United States using multiple satellite instruments. Atmos Environ 2008;42:6959–72.
[52] Grant N, Clarke A. Biomass––a burning issue––a discussion paper; 2010.
[53] Badescu V. Model of a thermal energy storage device integrated into a solar assisted heat pump system for space heating. Energy Convers Manage 2003;44:1589–604.
[54] Badescu V. Model of a solar-assisted heat-pump system for space heating integrating a thermal energy storage unit. Energy Build 2002;34:715–26.
[55] Hewitt N, Huang MJ. Defrost cycle performance for a circular shape evaporator air source heat pump. Int J Refrig 2008;31:444–52.
[56] Chua KJ, Chou SK, Yang WM. Advances in heat pump systems: a review. Appl Energy 2010;87:3611–24.
[57] The Energy Saving Trust. Getting warmer: a field trial of heat pumps, The Energy Saving Trust; 2010.
[58] U.S. Department of Energy, Energy Savers – Air-Source Heat Pumps, 2010; 2009.
[59] Ortiga J, Bruno JC, Coronas A, Grossman IE. Review of optimization models for the design of polygeneration systems in district heating and cooling networks. In: Valentin Pleşu, Paul Şerban Agachi, editors. Computer aided chemical engineering. Elsevier; 2007. p. 1121–6.
[60] Nilsson SF, Reidhav C, Lygnerud K, Werner S. Sparse district-heating in Sweden. Appl Energy 2008;85:555–64.
[61] Lund H, Möller B, Mathiesen BV, Dyrelund A. The role of district heating in future renewable energy systems. Energy 2010;35:1381–90.
[62] Nordell B, Hellström G. High temperature solar heated seasonal storage system for low temperature heating of buildings. Solar Energy 2000;69:511–23.
[63] Arefmanesh A, Dehghan AA, Dehghani AR. Thermal characteristics of an underground cold-water reservoir: analytical and experimental studies. Appl Therm Eng 2009;29:3261–5.
[64] Lund PD. The energy storage problem in low energy buildings. Solar Energy 1994;52:67–74.
[65] Roetzel A, Tsangrassoulis A, Dietrich U, Busching S. A review of occupant control on natural ventilation. Renew Sustain Energy Rev 2010;14:1001–13.
[66] Omer AM. Renewable building energy systems and passive human comfort solutions. Renew Sustain Energy Rev 2008;12:1562–87.
[67] Chan H, Riffat SB, Zhu J. Review of passive solar heating and cooling technologies. Renew Sustain Energy Rev 2010;14:781–9.
[68] Juodis E. Extracted ventilation air heat recovery efficiency as a function of a building's thermal properties. Energy Build 2006;38:568–73.
[69] Patania F, Gagliano A, Nocera F, Ferlito A, Galesi A. Thermofluid-dynamic analysis of ventilated facades. Energy Build 2010;42:1148–55.
[70] Brunsell JT. The performance of dynamic insulation in two residential buildings. Air Infiltration Rev 1995;16.
[71] Richman R, Pressnail KD. Quantifying and predicting performance of the solar dynamic buffer zone (SDBZ) curtain wall through experimentation and numerical modeling. Energy Build 2010;42:522–33.
[72] Entchev E, Gusdorf J, Swinton M, Bell M, Szadkowski F, Kalbfleisch W, et al. Micro-generation technology assessment for housing technology. Energy Build 2004;36:925–31.
[73] Staffell I, Baker P, Barton JP, Bergman N. UK microgeneration. Part II: technology overviews. Proceedings of the Institution of Civil Engineers: Energy 2010;163:143–65.

[74] Energy saving trust, potential for microgeneration: study and analysis by energy saving trust, econnect, and element energy; 2005.
[75] Lidula NWA, Rajapakse AD. Microgrids research: a review of experimental microgrids and test systems. Renewable and Sustainable Energy Reviews 2011;15:186–202.
[76] Brooks A, Lu E, Reicher D, Spirakis C, Weihl B. Demand dispatch. IEEE Power Energy Magazine 2010;8.
[77] Kushler M, Vine E, York D. Using energy efficiency to help address electric systems reliability: an initial examination of 2001 experience. Energy 2003;28:303–17.
[78] Moura PS, de Almeida AT. Multi-objective optimization of a mixed renewable system with demand-side management. Renewable and Sustainable Energy Reviews 2010;14:1461–8.